Search for formation of isospin-3/2 Ξ states by neutrinos

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Abstract

A narrow peak near 1870 MeV is observed in the combined invariant-mass spectrum of the systems $\Lambda K^0_S\pi^-$, $\Lambda K^0_S\pi^+$, $\Lambda K^-\pi^-$, and $\Lambda K^-\pi^+$ formed in ν_μ- and $\bar{\nu_\mu}$-induced charged-current collisions with free protons, deuterons, and Neon nuclei. Observed width of the resonance is consistent with being entirely due to apparatus smearing. A possible interpretation of the peak is formation and three-body $\Lambda K\pi$ decay of an exotic baryon with $I = 3/2$ and $S = -2$.

A narrow peak near 1862 MeV has been observed in invariant masses of the $\Xi^-\pi^-$ and $\Xi^-\pi^+$ systems formed in pp collisions [1], tentatively interpreted as a baryon state with $S = -2$ and $I = 3/2$ that is part of the (hypothesized) antidecuplet of pentaquark baryons [2]. Here, I report on a search for formation of this exotic baryon in neutrino and antineutrino collisions with free protons, deuterons, and neon nuclei. Instead of $\Xi^-\pi$, I analyze the system $\Lambda K\pi$ which may provide access to all four charge states of the $\Xi_{\bar{1}\bar{0}}$: $\Xi^+_{\bar{1}\bar{0}} \to \Lambda\bar{K^0}\pi^+$, $\Xi^0_{\bar{1}\bar{0}} \to \Lambda K^-\pi^+$, $\Xi^-_{\bar{1}\bar{0}} \to \Lambda\bar{K^0}\pi^-$, and $\Xi^{--}_{\bar{1}\bar{0}} \to \Lambda K^-\pi^-$. The system $\Lambda K\pi$ has a higher mass threshold than $\Xi\pi$, but on the other hand the smallness of observed $\Xi_{\bar{1}\bar{0}}$ width indicates that the kinematically favored decay $\Xi_{\bar{1}\bar{0}} \to \Xi\pi$ is subject to some dynamic suppression which may render the three-body $\Lambda K\pi$ channel competitive.

As in the previous search for formation of the $\Theta^+(1540)$ baryon [3], I analyze the data collected by several neutrino experiments with big bubble chambers—BEBC at CERN and the 15-foot chamber at Fermilab. Though logged several decades ago,

Experiment	WA21	WA25	WA59	E180	E632	Total
Chamber	BEBC	BEBC	BEBC	15' B.C.	15' B.C.	
Fill	Hydrogen	Deuterium	Neon–H_2	Neon–H_2	Neon–H_2	
Neutrinos:						
Mean E_ν, GeV	48.8	51.8	56.8	52.2	136.8	56.7
Mean $K^0_S(\Lambda)$ momentum, GeV	5.7(3.5)	5.7(3.4)	4.5(2.8)	3.4(1.9)	7.7(5.1)	5.3(3.3)
All CC events	18746	26323	9753	882	8550(5621)	64250
CC events with K^0_S	1050	1279	561	21	587	3498
CC events with Λ	442	644	378	19	352	1835
CC events with Λ and K^0_S	41	76	46	0	52	215
Antineutrinos:						
Mean E_ν, GeV	37.5	37.9	39.5	33.8	110.0	38.9
Mean $K^0_S(\Lambda)$ momentum, GeV	4.2(2.5)	4.2(2.0)	3.5(2.1)	3.4(1.4)	7.6(2.9)	4.0(2.1)
All CC events	13155	16314	15693	5927	1810(1190)	52900
CC events with K^0_S	702	761	631	231	123	2448
CC events with Λ	427	459	587	165	62	1700
CC events with Λ and K^0_S	56	62	58	17	6	199

Table 1: Relevant characteristics of the bubble-chamber neutrino data analyzed in this paper. For E632, I show either the actual number of measured CC events (in the parentheses) and the "equivalent" number that includes all CC events analyzed for V^0 emission.

bubble-chamber neutrino data are still unrivaled in quality and completeness. I rely on a database that comprises some 120 000 ν_μ- and $\bar{\nu}_\mu$-induced charged-current (CC) events on hydrogen, deuterium, and neon targets. In the past, these combined bubble-chamber neutrino data were employed in a number of physics analyses [4]. The database embraces the bulk of neutrino data obtained with BEBC (experiments WA21, WA25, and WA59) and a significant fraction of those collected with the 15-foot bubble chamber (experiments E180 and E632). Total numbers and mean energies of ν_μCC and $\bar{\nu}_\mu$CC events detected and reconstructed by the aforementioned experiments [5] are summarized in Table 1. Also shown are the statistics of CC events with reconstructed K^0_S mesons and Λ hyperons in the final state.

The bubble chamber is a good spectrometer, but provides virtually no identification for charged kaons. (Still, a few are identified by bubble density, range consistent with track curvature, and decay signature at endpoint.) Therefore, kaon mass is combinatorially assigned to any negative hadron for which the K^- hypothesis was not ruled out at the stage of kinematic reconstruction. I reject those ΛK^- subsystems that fall in the $\Sigma^-(1385)$

mass region as soon as the pion hypothesis is selected: $1355 < m(\Lambda\pi^-) < 1415$ MeV. The masses of all selected $\Lambda K^-\pi^\pm$ systems are plotted in Fig. 1. (Here and in what follows, I combine the neutrino and antineutrino data and those for all targets.) Despite the proximity of the $\Lambda K\pi$ mass threshold, including "assigned" K^- mesons is seen to result in a high level of combinatorial background. So I cut on an angle appropriate for 3-body decays, $\theta_{\rm norm}$. In the $\Lambda K\pi$ frame, the 3-momenta of the three daughters lie in the same decay plane, and $\theta_{\rm norm}$ is defined as the angle between the normal to this plane and the $\Lambda K\pi$ boost direction from lab. (Note that $\cos\theta_{\rm norm} = \pm 1$ corresponds to exactly transverse position of the decay plane with respect to the $\Lambda K\pi$ direction of motion.) Given an unpolarized parent, the signal should be uniformly distributed in $|\cos\theta_{\rm norm}|$. On the other hand, the mean value of $|\cos\theta_{\rm norm}|$ does not exceed 0.29 for all selected $\Lambda K^-\pi^\pm$ systems, since inclusive hadrons are largely emitted with small transverse momenta to the hadron jet. The effects of the selections $|\cos\theta_{\rm norm}| > 0.5$ and $|\cos\theta_{\rm norm}| > 0.7$ on the $\Lambda K^-\pi^\pm$ mass spectrum are shown in Fig. 1. Note that in a narrow region near 1870 MeV, the mass spectrum is less depleted by cutting on $|\cos\theta_{\rm norm}|$ than in the upstream and downstream regions. Since K^0_S mesons are reliably identified by $K^0_S \to \pi^+\pi^-$ decays, no $|\cos\theta_{\rm norm}|$ selection is applied to the $\Lambda K^0_S\pi^-$ and $\Lambda K^0_S\pi^+$ systems.

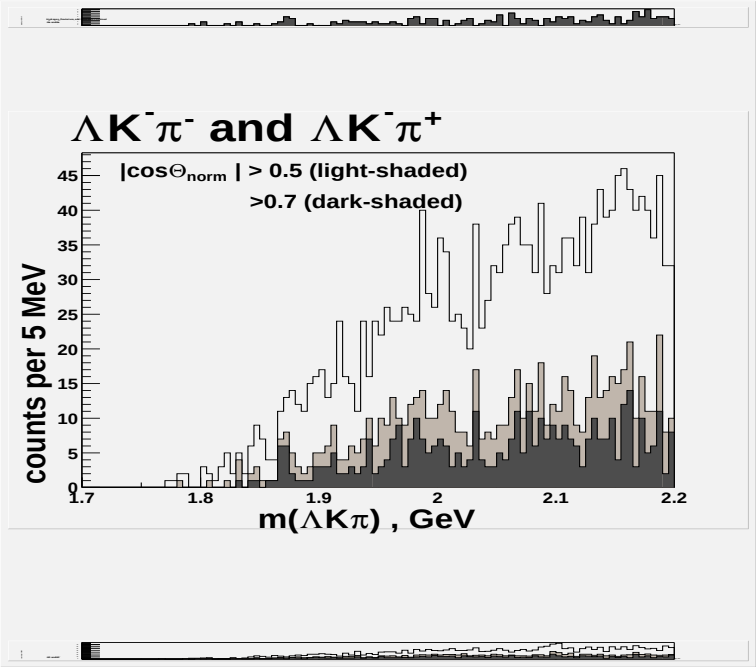

Figure 1: Invariant mass of the $\Lambda K^-\pi^-$ and $\Lambda K^-\pi^+$ systems combined. The light- and dark-shaded histograms result from the selections $|\cos\theta_{\rm norm}| > 0.5$ and $|\cos\theta_{\rm norm}| > 0.7$, respectively.

Invariant masses of selected $\Lambda K^0_S\pi^-$, $\Lambda K^0_S\pi^+$, $\Lambda K^-\pi^-$ ($|\cos\theta_{\rm norm}| > 0.5$), and $\Lambda K^-\pi^+$ ($|\cos\theta_{\rm norm}| > 0.5$) systems are separately plotted in Fig. 2. All four show small enhancements near 1870 MeV. And finally, in Figs. 3 ($|\cos\theta_{\rm norm}| > 0.5$) and 4 ($|\cos\theta_{\rm norm}| > 0.7$) I add up the mass spectra for all selected $\Lambda K^0_S\pi^\pm$ and $\Lambda K^-\pi^\pm$ systems, neglecting possible mass differences between the states of different charges. A distinct narrow enhancement is seen at $m(\Lambda K\pi) \simeq 1870$ MeV. The "grand-total" $m(\Lambda K\pi)$ spectrum is then fitted to a Gaussian on top of a third-order polynomial, see the middle panels of Figs. 3 and 4. Either fit returns a central mass value slightly in excess of 1870 MeV and an rms width of $\sigma \simeq 4 \pm 1$ MeV. The observed width is consistent with being entirely due to apparatus smearing of $m(\Lambda K\pi)$, estimated as ~ 5 MeV using individual errors for live events in the peak region. Statistical significance of the putative signal, (optimistically) estimated as $S/\sqrt{B}$ over the mass region of $\pm 2\sigma$ around the peak position, is over 8 standard deviations.

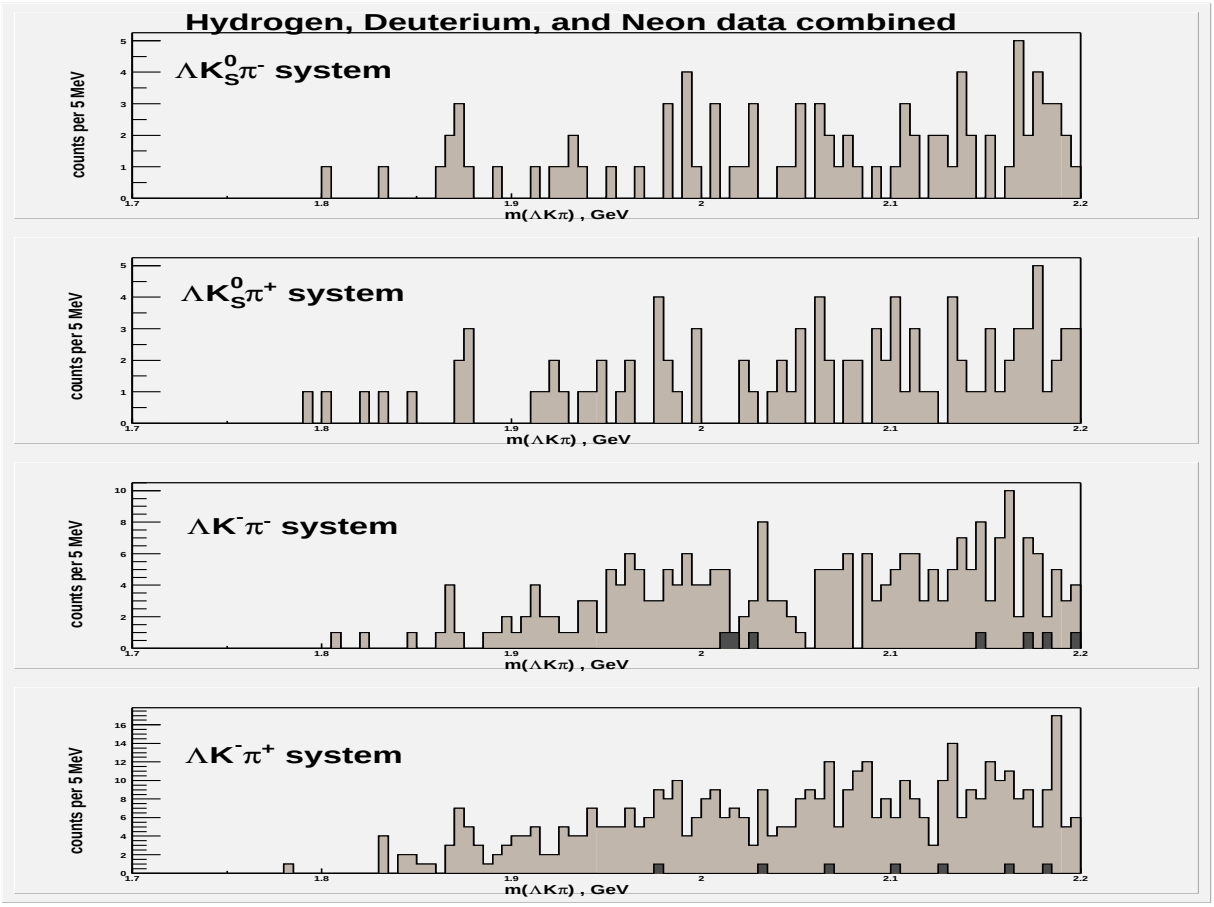

Figure 2: The $\Lambda K^0_S\pi^-$, $\Lambda K^0_S\pi^+$, $\Lambda K^-\pi^-(|\cos\theta_{\rm norm}| > 0.5)$ and $\Lambda K^-\pi^+$ ($|\cos\theta_{\rm norm}| > 0.5$) mass distributions. Dark-shaded histograms are for identified charged kaons.

Two events in the peak have K^0_S mesons among the secondaries emitted in association with the $\Lambda K\pi$ system, and yet another one — an associated charged kaon which is a K^+ identified in neon, see Fig. 3. Had two $s\bar{s}$ pairs been produced per (anti)neutrino collision, one would expect $\sim 6 \pm 3$ events with associated K^0_S mesons from fragmentation of the two $\bar{s}$ quarks. Note however that two s quarks may also result from a strangeness-changing transition $u \to s$ accompanied by creation of a single $s\bar{s}$ pair.

In summary, a narrow peak near 1870 MeV is observed in the combined invariant-mass spectrum of the systems $\Lambda K^0_S\pi^-$, $\Lambda K^0_S\pi^+$, $\Lambda K^-\pi^-$, and $\Lambda K^-\pi^+$ formed in ν_μ- and $\bar{\nu_\mu}$-induced CC collisions with free protons, deuterons, and Neon nuclei. Observed width of

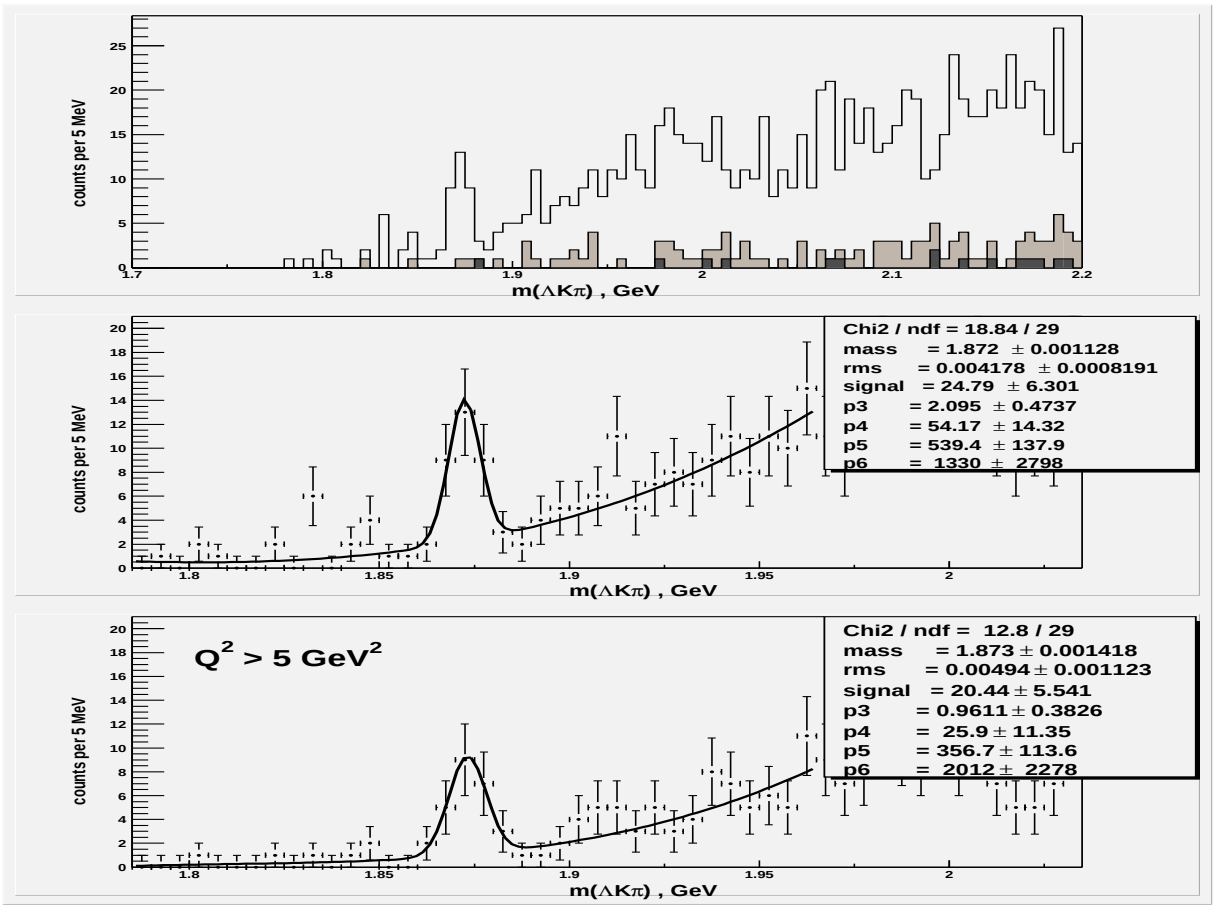

Figure 3: The $\Lambda K^0_S\pi^-$, $\Lambda K^0_S\pi^+$, $\Lambda K^-\pi^-(|\cos\theta_{\rm norm}| > 0.5)$, and $\Lambda K^-\pi^+$ $(|\cos\theta_{\rm norm}| > 0.5)$ mass spectra added up for all Ne+H_2+D_2 data (top panel). The light- and dark-shaded areas are the contributions from events with additional K^0_S mesons and identified charged kaons, respectively. Shown in the middle panel is a Gaussian fit of the combined $m(\Lambda K\pi)$ spectrum. The effect of an additional selection $Q^2 > 5$ GeV^2 is illustrated in the bottom panel.

the putative $\Lambda K\pi$ resonance is consistent with being entirely due to apparatus resolution. A possible interpretation of the peak is formation and $\Lambda K\pi$ decay of an exotic baryon with $I = 3/2$ and $S = -2$. Our results may support the earlier observation of a $\Xi^-\pi^\pm$ resonance near 1862 MeV in pp collisions [1], provided that the discrepancy of $\sim$10 MeV between the masses of the two resonances can be explained by systematic effects.

I thank the WA21, WA25, WA59, E180, and E632 Collaborations for providing excellent neutrino data whose physics potential is still far from exhausted. Thanks are also due to Prof. Ya.I. Azimov and Dr. I.I. Strakovsky for useful comments and stimulating discussions.

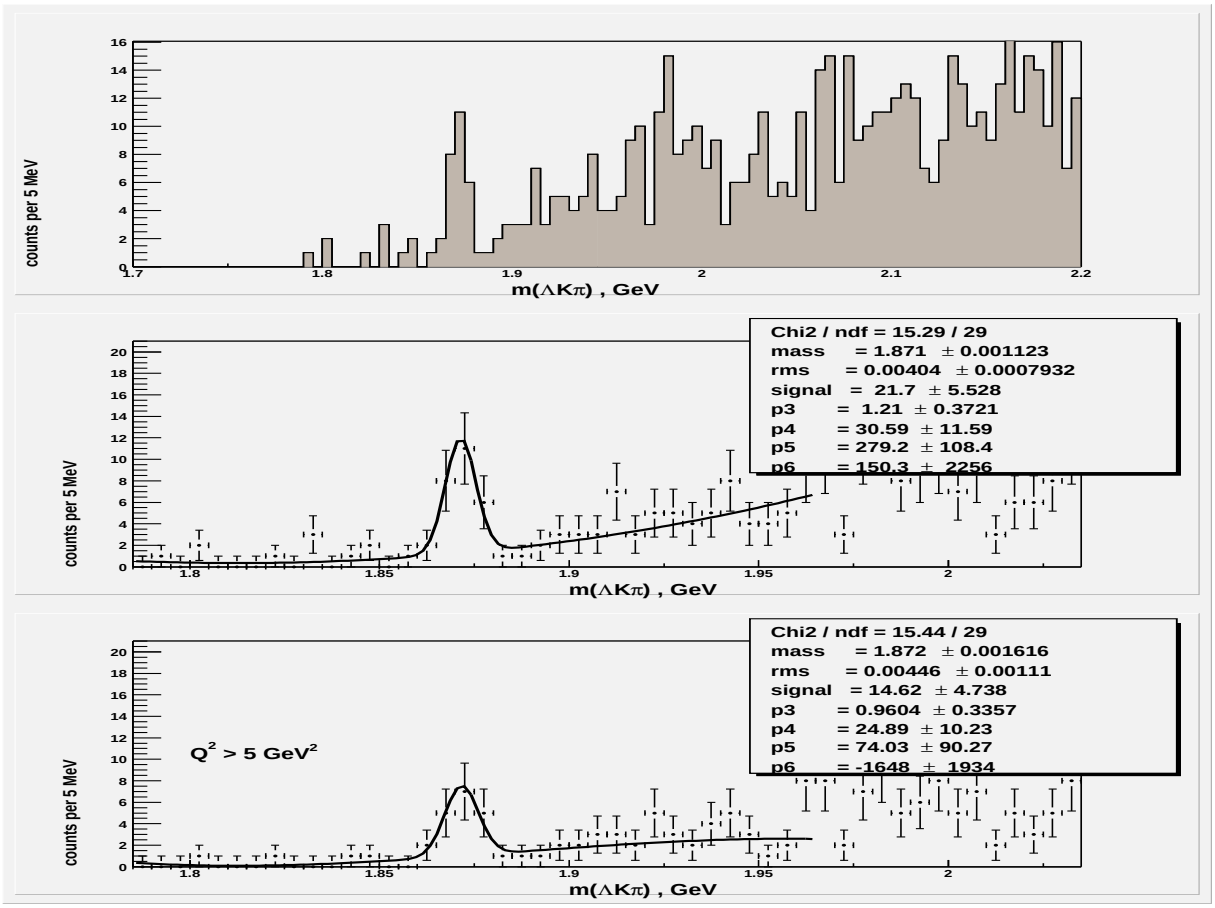

Figure 4: Similar data as in Fig. 3, but with a tighter selection $|\cos\theta_{\rm norm}| > 0.7$ for the $\Lambda K^-\pi^-$ and $\Lambda K^-\pi^+$ systems.

References

[1] C. Alt et al. (NA49 Coll.), Phys. Rev. Lett. 92, 042003 (2004).

[2] D. Diakonov, V. Petrov, and M. Polyakov, Z. Phys. A359, 305 (1997).

[3] A.E. Asratyan, A.G. Dolgolenko, and M.A. Kubantsev, Yad. Fiz. 67, 1 (2004) [Phys. At. Nucl. 67, 682 (2004)], hep-ex/0309042.

[4] A.E. Asratyan et al., Phys. Lett. 257B, 525 (1991);
A.E. Asratyan et al. (Big Bubble Chamber Neutrino Coll.), Z. Phys. C58, 55 (1993);
V.A. Korotkov et al. (Big Bubble Chamber Neutrino Coll.), Z. Phys. C60, 37 (1993);
V.G. Zaetz et al. (Big Bubble Chamber Neutrino Coll.), Z. Phys. C66, 583 (1995).

[5] G.T. Jones et al. (WA21 Coll.), Z. Phys. C51, 11 (1991);
D. Allasia et al. (WA25 Coll.), Z. Phys. C37, 527 (1988);
S. Willocq et al. (WA59 Coll.), Z. Phys. C53, 207 (1992);
V.V. Ammosov et al. (E180 Coll.), Nucl. Phys. B177, 365 (1981);
D. DeProspo et al. (E632 Coll.), Phys. Rev. D50, 6691 (1994).